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PREDICTING THE NOISE RADIATION FROM BUILT UP MACHINERY STRUCTURES - AN ENGINEERING APPROACH USING STATISTICAL ENERGY ANALYSIS

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INTRODUCTION

Most machinery structures are built up from a number of component parts which are coupled together in some way - normally by bolting or welding. Once the structure is excited into vibration by the working of other forces, vibrational energy will distribute itself throughout the structure being transmitted each of the component parts which then respond and radiate sound. An initial step in the study of the noise radiation from a particular machine is generally to identify how much sound energy is being radiated by the individual parts of the structure so that the areas radiating the majority of the sound can be determined. Numerous techniques have been developed to separate out the noise from specific regions on a structure ranging from simple techniques of component removal or partial cover to the measurement techniques of surface velocity and sound intensity and to the signal processing techniques of multiple coherence and correlation methods. However, these are all measurement techniques and do not allow any prediction of the effects of changing the structure in any way.

Energy accountancy methods[1] have been developed to give a predictive technique for noise control engineering purposes. The method is based on the energy balance between the vibrational energy which is input, E_{IN}, to the structure and that which is dissipated either within the structure, E_{diss}, or radiated as sound, E_{RAD}.

i.e. $E_{IN} = E_{diss} + E_{RAD}$ or $E_{RAD} = E_{IN} - E_{diss}$

To apply this technique to the sound radiation from the component parts of a built up structure it is necessary to consider not only the total input energy and the structural and acoustical characteristics of each part but also the way in which the vibrational energy distributes itself throughout the structure.

As most machinery structures are generally of such dimensions that the majority of the sound radiation occurs in the regions of high modal densities, classical methods of vibrational analysis or finite element methods are inappropriate to predict the distributions of vibrational energy. Statistical methods can offer a more practical approach. Statistical Energy Analysis (SEA) techniques have been developed by Lyon, Fahy[2,3] and others for many structural vibration and structural-acoustic interaction applications.

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SEA is based upon a set of power balance equations linking the component parts (subsystems) of a coupled system. At a particular subsystem vibrational energy is either dissipated due to internal damping (or radiated as sound) or transmitted to other subsystems as indicated in figure 1 for two subsystems. The amount of energy transfer between components depends on the coupling between the particular components and is represented by the coupling loss factors.

The linking of SEA and energy accountancy ideas (both based upon similar ideas of energy balance) is developed in detail in reference 4 and leads to the total sound radiation from a built up structure to be given by:

$$W_{rad} = W^{i}_{rad} \left[1 + \sum_{\substack{j=1 \\ j\neq i}}^{N} \frac{E_j}{E_i} \frac{\sigma^{j}_{rad}}{\sigma^{i}_{rad}} \cdot \frac{d_i}{d_j} \right]$$

Where suffix j = subsystem no; i - excited subsystem ; d = thickness; E = energy ratio.

Example 1 - Experiments on a two-plate structure

As an initial proving exercise the methods were applied to predict the noise radiation from a simple two-plate structure. Predictions were made for the plates in both undamped and damped conditions and compared with the sound power radiation calculated from direct measurements of $\langle \bar{v}^2 \rangle$ on the individual plates. Both stead state and transient excitation was used.

For the measurements the structure was suspended by three light lines as shown in figure 2. The internal loss factors of each separate plate both in the undamped and damped condition had been measured before welding together, the plates being damped by a proprietary stick-on damping sheet.

For steady state excitation the plates were driven using a light coil and magnet arrangement using a white noise source filtered in one-third octave bands. Vibration measurments were made using an accelerometer and digital signal analyser, surface velocity being obtained by integration of the respective acceleration spectrum. A desk-top scientific computer was used for data manipulation and the SEA computations. Measurements were also made with transient excitation using a steel impacting mass swung through a fixed pendulum arc to achieve a constant impact force.

Figures 3a-c show the predicted and measured sound power for the condition where the smaller plate - plate 2 - was excited. In this condition the majority of the total sound radiated is from plate 1 - the part of the structure indirectly excited. Thus the greater part of the total sound radiation is due to transfer of vibrational energy from the point of excitation into another more highly radiative part of the structure. This is a common occurrence in many machinery structures where the working forces may be applied to some solid thick part of the structure, but the majority of sound radiation is from thinner outer surfaces with larger radiating areas. In each case the predicted results are shown compared with the sound power obtained from actual measurements of the surface velocity of the plates. The results show generally good agreement (within 3 dB overall). It must be noted, however, that as a starting point for the SEA calculations an actual measurement of the vibrational energy of the excited plate is used. Therefore the predicted sound radiation from the excited plate in its original condition (a) should be identical with the measured results as they are in fact both derived from the same measurement. Some very slight differences are apparent in the results but this is only due to the different computational routines used for the calculations.

Example 2 - Predicting noise reductions on a scale model of a punch press

The techniques have been applied to predict the changes in noise radiation occurring as individual parts of a press structure were damped. A $\frac{1}{5}$ scale model of a 200 tonne straight sided press was used for the experimental work in the investigation, individual parts of the structure being damped by filling the hollow sections with sand.

An important factor when applying these techniques to a practical structure is in the definition of individual subsyutems. Each of the subsystems must be characterized by an internal loss factor, coupling loss factor and modal density and for the calculation of sound energy a radiation efficiency. When modelling a system it is necessary to: identify the characteristics of energy flow and storage within the system, to define the regions into which the input power is applied and the paths through which appreciable energy may flow. However, some concessions have to be made between complexity of the model and representation of the structure. Two slightly different representations were used, to represent the press model: a six subsystem SEA network, figure 4(a), and an eight subsystem network, figure 4(b).

The excitation of the structure of a power press during the blanking or piercing of metal further complicates the appliation of SEA. This excitation is a transient release of stored strain energy from the structure which occurs as the workpiece material fractures. Thus the true energy input is not a steady state energy flow into one substructure as is assumed in simplified SEA representation, but rather the transient release of the initial strain energy

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which is stored throughout all the components of the structure. In practice the most important energy inputs will be from those components which store the maximum strain energy. For simplicity in this analysis it is assumed that the enrgy input was to the bed plate only, i.e. applied in a position just below the tool.

Predicted and measured noise reductions for the model, with various parts damped, are shown in figures 5 a to c. The predictions generally agree well with measured reductions within 3 dB in most instances. However, for the case of the sides only damped, there is some disagreement between predicted and measured results, especially for the eight subsystem model. It is considered that this is because of the difficulties of accurately representing the complexly shaped thin side panels of the press model in the analysis. For this reason the six subsystem representation, where the side panels were lumped with the side plates, in general gave better agreement with measured reductions.

CONCLUSIONS

Experimental results have shown that quite good predictions of the noise radiation from the individual parts of a built up structure can be obtained by the use of Energy accountancy and SEA ideas. This is especially useful for the prediction of the effects (and optimisation) of modifications to reduce overall noise radiation, e.g. increased damping of specific parts, changes of component dimensions, method of connection, etc. The accuracy of the results depends largely upon the accuracies to which the individual parameters can be evaluated. Accurate evaluation of coupling loss factors and radiation efficiencies can be especially difficult on the complexly shaped and connected component parts of many machinery structures. However, both theoretical and empirical data may be used and various measurements made at each stage in the analysis to check results.

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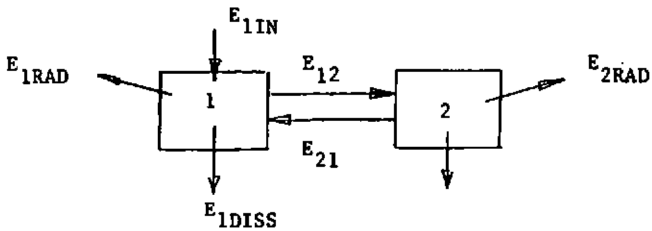


FIG. 1: 2 Subsystem SEA model

FIG. 2 - EXPERIMENTAL TWO-PLATE STRUCTURE

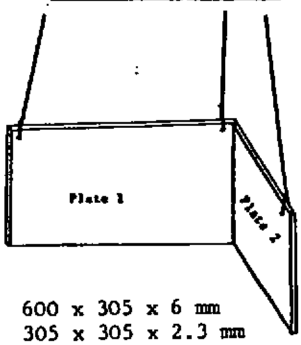
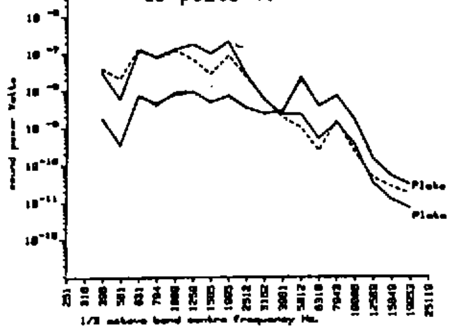


Plate 1: 600 x 305 x 6 mm
Plate 2: 305 x 305 x 2.3 mm

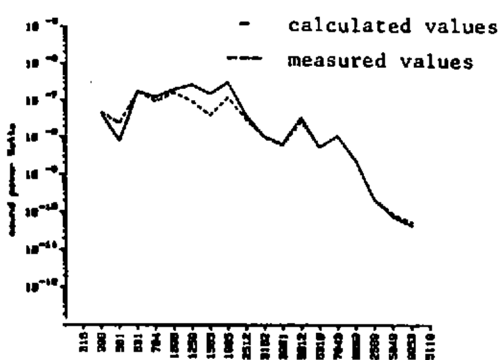
FIG. 3 - SOUND POWER FROM PLATES -

Steady state excitation to plate 2.



(a) only plate 2 damped

(b) Plates 1 and 2 damped.



(c) Total sound power - plates 1 and 2 damped.

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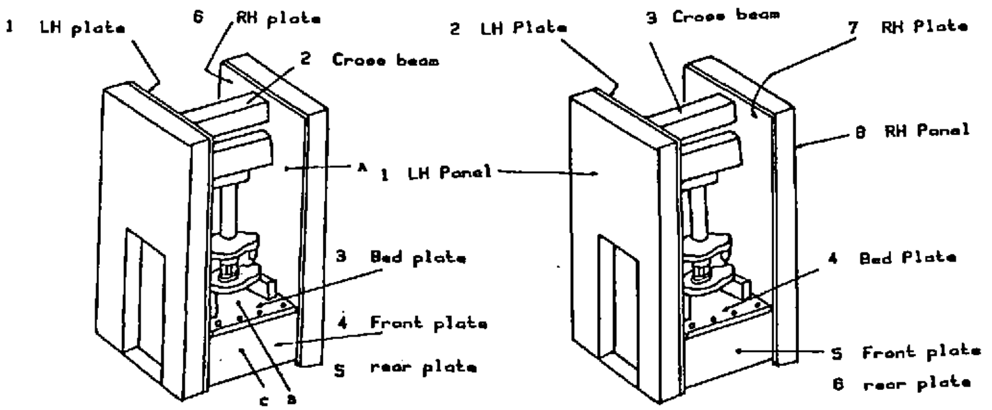
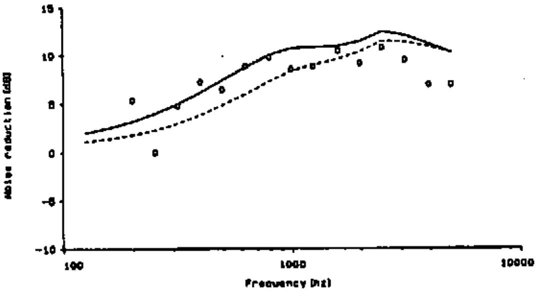


(a) Six subsystem representation (a) Eight subsystem representation

FIG. 4 SEA REPRESENTATIONS OF PUNCH PRESS MODEL

FIG. 5 NOISE REDUCTIONS ON THE MODEL



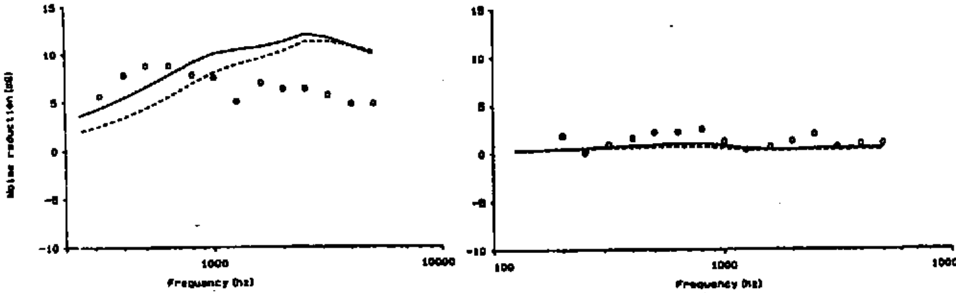
Predicted values

--- 8 subsystems

—— 6 subsystems

o o measured values.

(a) sides and bed area damped



(b) sides only damped

c) bed area only damped